



ATTACHMENT 36

Consideration in Groundwater Remediation at Superfund Sites U.S. EPA Draft Memorandum



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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

MEMORANDUM

SUBJECT: Considerations in Ground-Water Remediation at Superfund Sites -- Update

FROM: Don R. Clay
Assistant Administrator

TO: Waste Management Division Directors
Regions I, IV, V, VI, VII, VIII
Emergency and Remedial Response Division Director
Region II
Hazardous Waste Management Division Directors
Region III, IX
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Region X

Purpose

The purpose of this Directive is to clarify Superfund's approach to remediating contaminated ground water and to summarize on-going activities designed to address some of the more complex problems associated with ground-water remediation.

Background

Ground-water contamination is one of the most prevalent and challenging problems for Superfund, affecting more than 70% of the sites on the National Priorities List. The Office of Emergency and Remedial Response (OERR), completed a study in 1989 which was designed to evaluate the performance of ground-water extraction systems. The study focused on 19 sites that had operating ground-water extraction systems. Recently, an update and expansion of this study has been completed. The findings

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from the extraction evaluation study,^{1,2} and subsequent studies by EPA and others have identified factors that, in some cases, appear to impede the ability of currently available technologies to restore contaminated ground water to its beneficial uses throughout the contaminated area. There has been confusion over the implications of these findings and EPA policy as outlined in recent Directives^{3,4}.

Objective

The objective of this Directive is to ensure a consistent and sound approach to ground-water remediation at Superfund sites by: 1) clarifying the Superfund position on remediation of contaminated ground water, and 2) identifying projects currently underway that will improve our response to contaminated ground water.

Implementation

I. Superfund Ground-Water Policy

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the implementing regulation, the National Contingency Plan (NCP), the cleanup goal for contaminated ground water is to return ground water to its beneficial uses within a reasonable time frame where practicable. This premise underlies all remedies designed to address contaminated ground water at Superfund sites. Experience and

¹ U.S. EPA, Evaluation of Ground-Water Extraction Remedies EPA/540/2-89/054, Office of Emergency and Remedial Response, September 1989.

² U.S. EPA, Evaluation of Ground-Water Extraction Remedies: Phase II Preprint, Office of Emergency and Remedial Response, September 1991.

³ U.S. EPA, "Considerations in Ground-Water Remediation at Superfund Sites" Directive No. 9355.4-03, Office of Solid Waste and Emergency Response, October 18, 1989.

⁴U.S. EPA, "Suggested ROD Language for Various Ground-Water Remediation Options" Directive 9283.1-03, Office of Solid Waste and Emergency Response, October 10, 1990.

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research support the following additional guidelines:

1. Adequate site characterization data is essential to understanding and effectively remediating contaminated ground water. One of the primary findings in the studies of actual system performance is that there is rarely sufficient information available to fully understand how contaminants are moving in the subsurface. It is essential to have an accurate picture of the subsurface environment and contaminant form and distribution. Attachment 1 provides a summary of site characterization data pertinent to evaluating ground-water remedies.
2. Aqueous phase plumes should be contained early. It is generally feasible and desirable to implement a containment system; e.g. pumping for gradient control, once the general plume definition phase is complete. This prevents the contamination from spreading further into uncontaminated ground water, thus limiting the area for which remedial action may be required.
3. The presence of non-aqueous phase liquids (NAPLs) should be evaluated. Contaminants present as an immiscible phase in the saturated zone can substantially complicate investigation and cleanup, particularly where these contaminants are more dense than water⁵. Certain factors can provide an indication that contaminants are present as an immiscible phase and should generally be evaluated prior to initiating field investigatory work. Attachment 2 provides a summary of these factors and outlines a process for determining the likelihood that DNAPLs are present.
4. If NAPLs are encountered in a well, they should generally be removed directly by pumping the immiscible phase. It is often very difficult to locate dense NAPLs (DNAPLs) due to their ability to move vertically through small discontinuities in the subsurface environment. However, where they are encountered they should generally be extracted since it is more effective to remove the immiscible liquid directly than extract it as it solubilizes into the aqueous phase.

⁵ U.S. EPA, Dense Nonaqueous Phase Liquids EPA 540/4-91-002, Office of Research and Development/Office of Solid Waste and Emergency Response, March 1991.

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5. Extraction systems should be monitored carefully and modified as appropriate to improve effectiveness and efficiency. Once a ground-water extraction system is implemented, samples should be collected and analyzed periodically from wells located throughout the contaminated zone to assess the plume response to extraction and determine the need to modify the system during operation⁶.
6. Where it is determined that it is not practicable to restore portions of the contaminated ground water with currently established technology, due to the presence of DNAPLs, alternate actions, including containment and shrinking of the contaminated area should be implemented. In some cases, evidence will indicate that DNAPLs are present in the ground water in localized areas. It may not be technically practicable to return the ground water in those areas to its beneficial uses. It is important to ensure that these areas are managed to prevent expansion and migration into uncontaminated ground water for as long as the concentrations remain above levels corresponding to the beneficial uses. This likely will require gradient control to prevent migration of aqueous-phase contamination (and extraction of the DNAPLs when technically feasible). A technical impracticability waiver is needed for the ground water that will not be restored to its beneficial uses.

Efforts should be made to reduce the size of the contaminated area to the extent practicable prior to implementing a containment remedy. Based on evidence collected from operating ground-water extraction systems, contaminated areas can be substantially reduced in size and large volumes of contaminant mass removed, even in cases where portions of the plume may not be fully restored using current technology. This generally involves pumping and treating aqueous phase contamination that is migrating away from the zone in which the DNAPL is located.

Because of the long-term costs and liability of maintaining a ground-water containment system, it will be beneficial to consider innovative technologies as

⁶ U.S. EPA, Suggested Practices for Remedial Operation and Performance Evaluations, Robert S. Kerr Environmental Research Laboratory, pre-print.

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they are developed to clean up those portions of the plume that are being contained.

II. On-Going Activities

There are many recently initiated projects focussed on addressing some of the difficult ground-water cleanup scenarios. A workshop of experts in the area of DNAPL movement and cleanup was held last spring. Proceedings summarizing the general consensus of this group should be available this fall. OERR is supporting a long-term research effort by the Robert S. Kerr Environmental Research Laboratory (RSKERL) to evaluate innovative technologies that will be effective in removing NAPLs from the subsurface. OERR will be working closely with RSKERL to develop guidances on site characterization, remediation, and performance monitoring for DNAPL contaminated sites over the next year.

OERR is also supporting a National Research Council (NRC) study, "Alternatives for Reducing Risk from Existing Ground-Water Contamination" that will assess the current opinions and experiences with ground-water remediation and look at alternative approaches.

Finally, OERR will continue to learn from program experience. Many ground-water remediation systems are now in design and construction, so our data base will grow significantly over the next few years. We will be monitoring these systems closely and will continue to improve our approach to assessing and remediating contaminated ground water.

If you would like additional information please contact Jennifer Sutter (Hazardous Site Control Division) at FTS 398-9363 or Lynn Deering (OERR) at FTS 245-4063.

Attachments

See attached about unsolicited grants!!

ATTACHMENT 1

Data Pertinent to Evaluating Remedial Actions for Contaminated Ground Water -- Gaps Identified in the Evaluation of Ground Water Extraction Remedies Phase I and II

Hydrogeologic Information

1. Number of aquifers and degree of hydraulic connection between them
2. Location and continuity of lower permeability zones
3. Hydraulic conductivity of each aquifer
4. Yield of each aquifer
5. Stratigraphy -- continuous coring at select wells
5. For NAPL-contaminated sites, additional information can be important (presented in order of increasing difficulty to obtain):
 - o Grain size analysis to obtain rough predictions of NAPL holding and transmitting capacity
 - o Porosity
 - o The relationship between the degree of saturation, the capillary pressure, and the relative permeability for the wetting and nonwetting fluids
 - o Residual saturation for NAPL
6. Potentiometric gradients

Contaminant Characteristics

1. Location and definition of the source(s) both horizontally and vertically within the defined site and verification that there are no other major sources outside the defined site.
2. Type of waste and form -- likely presence as NAPL
3. Solubilities of compounds
4. Miscibility of various contaminants -- potential presence as multi-component NAPL
5. Concentrations of contaminants in soil and ground water -- vertical and horizontal extent of contaminant plume
6. Vertical variations in contaminant concentrations
7. Sorption of contaminants to soil, evaluated through (in decreasing level of accuracy) column studies, batch analysis of sorbed concentrations, or partition coefficient/organic carbon content estimate
8. Presence of NAPLs in ground water samples using interface probe or clear bailer

Remediation Performance Evaluation

1. Piezometers on downgradient side of extractions wells
2. Changes in vertical and horizontal extent of contaminant plume as a result of remediation
3. Hydraulic effects of extraction -- water level data
4. Mass of contaminants removed by individual extractions wells

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Estimating Potential for Occurrence of DNAPL at Superfund Sites

Quick Reference Fact Sheet

GOALS

The presence of Dense Non-Aqueous Liquids (DNAPLs) in soils and aquifers can control the ultimate success or failure of remediation at a hazardous waste site. Because of the complex nature of the DNAPL transport and fate, however, DNAPL may be undetected by direct methods, leading to poor site assessments and inadequate remedial designs. Sites affected by DNAPL may require a different "paradigm," or conceptual framework, to develop effective characterization and remedial actions (4).

To help site personnel determine if DNAPL-based characterization strategies should be employed at a particular site, a qualitative method for estimating the potential for DNAPL occurrence was developed. Two sources of existing site information are used:

- Historical Site Use Information
- Site Characterization Data

By using available data, site RPMs and other decision makers can enter a system of two flowcharts and a classification matrix for estimating the potential for DNAPL occurrence at a site. If the potential for DNAPL occurrence is low, then conventional site assessment and remedial actions may be sufficient. If the potential for DNAPL is moderate or high, however, a different conceptual approach may be required to account for problems associated with DNAPL in the subsurface.

BACKGROUND

DNAPLs are separate-phase hydrocarbon liquids that are denser than water, such as chlorinated solvents, wood preservative wastes, coal tar wastes, and pesticides. Until recently, standard operating practice in a variety of industries resulted in the release of large quantities of DNAPL to the subsurface. Most DNAPLs undergo only limited degradation in the subsurface, and persist for long periods while slowly releasing soluble organic constituents to groundwater through dissolution. Even with a moderate DNAPL release, dissolution may continue for hundreds of years under natural conditions before all the DNAPL is dissipated and concentrations of soluble organics in groundwater return to background levels.

DNAPL exists in two states in the soil/aquifer matrix: free phase DNAPL and residual DNAPL. When released at the surface, free phase DNAPL moves downward through the soil matrix under the force of gravity or laterally along the surface of sloping fine-grained stratigraphic units. As the free phase DNAPL moves, blobs or ganglia are trapped in pores and/or fractures by capillary forces (12). The amount of the trapped DNAPL, known as residual saturation, is a function of the physical properties of the DNAPL and the hydrogeologic characteristics of the aquifer medium and ranges up to 50% of total pore volume (18).

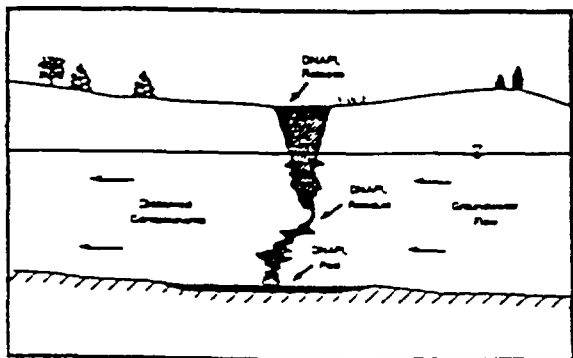
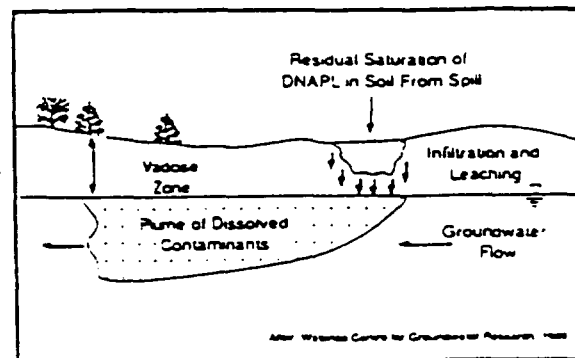
Once in the subsurface, it is difficult or impossible to recover all of the trapped residual DNAPL. The conventional aquifer remediation approach, groundwater pump-and-treat, usually removes only a small fraction of trapped residual hydrocarbon (27). Although many DNAPL removal technologies are currently being tested, to date there have been no field demonstrations where all of the released DNAPL has been successfully recovered from the subsurface. The DNAPL that remains trapped in the soil/aquifer matrix acts as a continuing source of dissolved organics to groundwater, preventing the restoration of DNAPL-affected aquifers to drinking water standards for many years.

DNAPL TRANSPORT AND FATE - CONCEPTUAL APPROACHES

The major factors controlling DNAPL migration in the subsurface include (7): 1) the volume of DNAPL released; 2) the area of infiltration; 3) the duration of release; 4) DNAPL properties such as density, viscosity, etc.; and 5) properties of the aquifer media such as pore size, presence of aquitards, and fractures etc. To describe the general transport and fate properties of DNAPL in the subsurface, a series of conceptual models (11) are presented in the following figures.

Case 1: DNAPL Release to Unsaturated Zone Only

After release on the surface, DNAPL moves vertically downward under the force of gravity and soil capillarity. Because only a small amount of DNAPL was released, all of the mobile DNAPL is eventually trapped in pores and fractures in the unsaturated zone. Infiltration through the DNAPL zone dissolves some of the soluble organic constituents in the DNAPL, carrying organics to the water table and forming a dissolved organic plume in the aquifer.

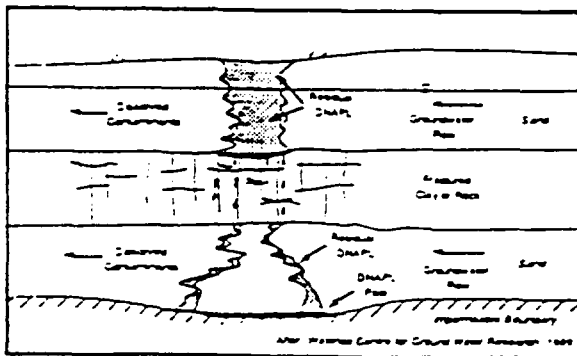
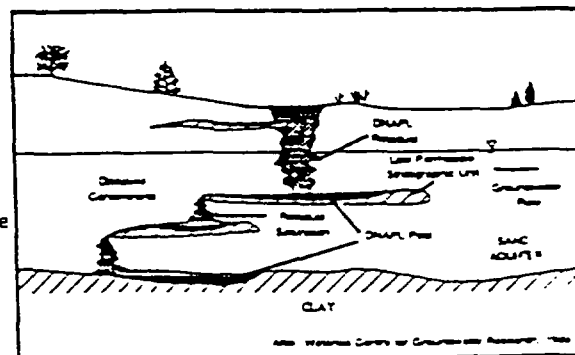


Case 2: DNAPL Release to Unsaturated and Saturated Zones

If enough DNAPL is released at the surface, it can migrate all the way through the unsaturated zone and reach a water-bearing unit. Because the specific gravity of DNAPL is greater than water, it continues downward until the mobile DNAPL is exhausted and is trapped as a residual hydrocarbon in the porous media. Groundwater flowing past the trapped residual DNAPL dissolves soluble components of the DNAPL, forming a dissolved plume downgradient of the DNAPL zone. As with Case 1, water infiltrating down from the source zone also carries dissolved constituents to the aquifer and contributes further to the dissolved plume.

Case 3: DNAPL Pools and Effect of Low-Permeability Units

Mobile DNAPL will continue vertical migration until it is trapped as a residual hydrocarbon (Case 1 and Case 2) or until low-permeability stratigraphic units are encountered which create DNAPL "pools" in the soil/aquifer matrix. In this figure, a perched DNAPL pool fills up and then spills over the lip of the low-permeability stratigraphic unit. The spill-over point (or points) can be some distance away from the original source, greatly complicating the process of tracking the DNAPL migration.

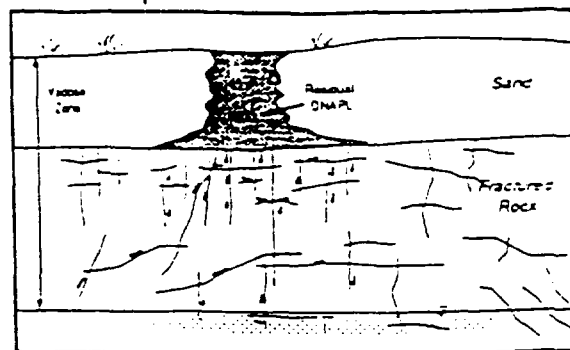


Case 4: Composite Site

In this case study, mobile DNAPL migrates vertically downward through the unsaturated zone and the first saturated zone, producing a dissolved constituent plume in the upper aquifer. Although a DNAPL pool is formed on the fractured clay or rock unit, the fractures are large enough to permit vertical migration downward to the deeper aquifer (see Case 5, below). DNAPL pools in a topographic low in the underlying impermeable unit and a second dissolved constituent plume is formed

Case 5: Fractured Rock or Fractured Clay System

DNAPL introduced into a fractured rock or fractured clay system follows a complex pathway based on the distribution of fractures in the original matrix. The number, density, size, and direction of the fractures usually cannot be determined due to the extreme heterogeneity of a fractured system and the lack of economical aquifer characterization technologies. Relatively small volumes of DNAPL can penetrate deeply in fractured systems due to the low retention capacity of the fractures and the ability of DNAPL to migrate through very small (~10 micron) fractures. Many clay units, once considered to be relatively impermeable to DNAPL migration, often act as a fractured media with preferential pathways for vertical and horizontal DNAPL migration.



Occurrence of DNAPL - Decision Chart 1

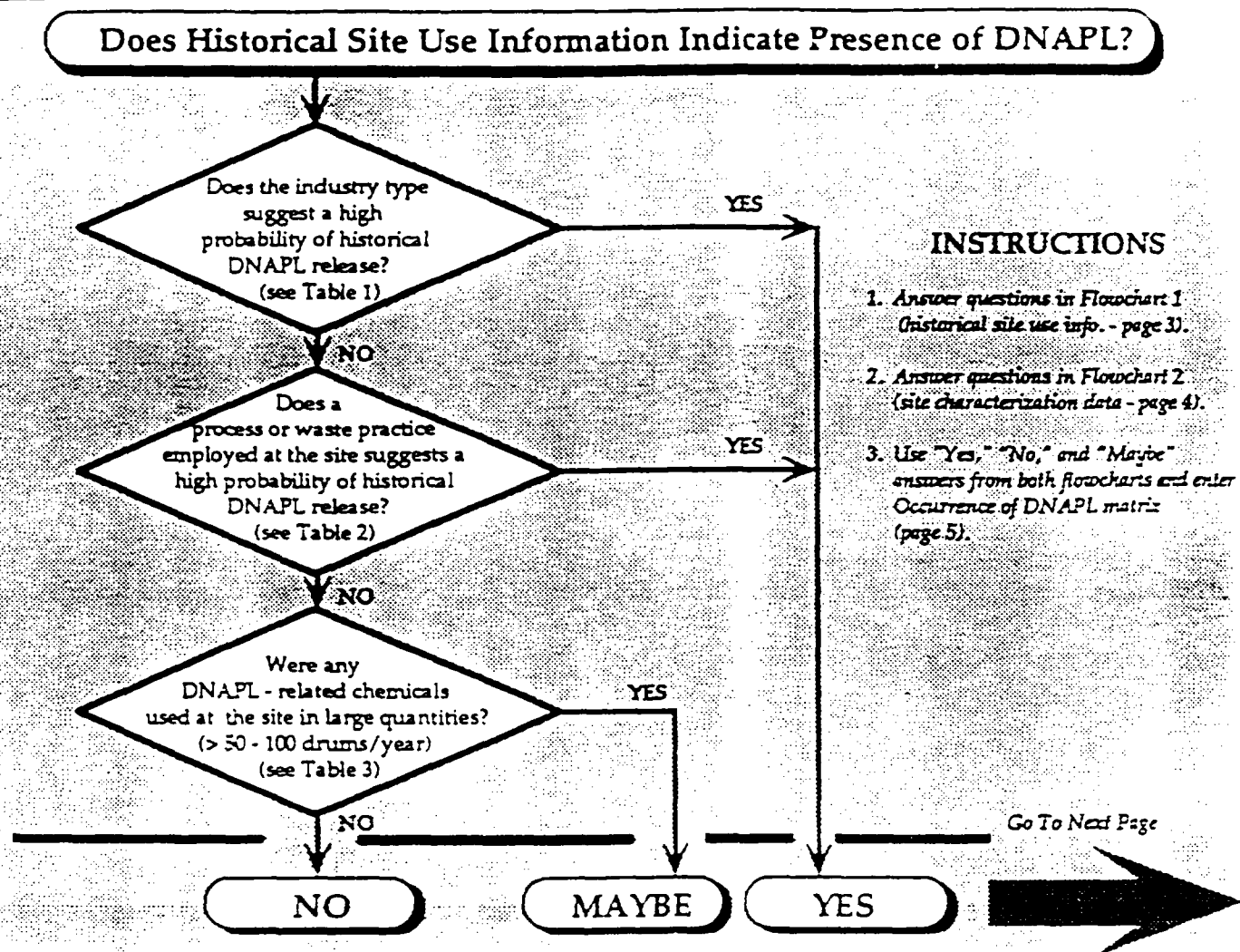


TABLE 1

Industries with high probability of historical DNAPL release:

- Wood preservation (creosote)
- Old coal gas plants (mid-1800s to mid-1900s)
- Electronics manufacturing
- Solvent production
- Pesticide manufacturing
- Herbicide manufacturing
- Airplane maintenance
- Commercial dry cleaning
- Instrument manufacturing
- Transformer oil production
- Transformer reprocessing
- Steel industry coking operations (coal tar)
- Pipeline compressor stations

TABLE 2

Industrial processes or waste disposal practice with high probability of historical DNAPL release:

- Metal cleaning/degreasing
- Metal machining
- Tool-and-die operations
- Paint removing/stripping
- Storage of solvents in underground storage tanks
- Storage of drummed solvents in uncontained storage areas
- Solvent loading and unloading
- Disposal of mixed chemical wastes in landfills
- Treatment of mixed chemical wastes in lagoons or ponds

TABLE 3 DNAPL-Related Chemicals (1):

Halogenated Volatiles	Non-Halogenated Semi-Volatiles
Chlorobenzene	2-Methyl Naphthalene
1,2-Dichloropropane	o-Cresol
1,1-Dichloroethane	p-Cresol
1,1-Dichloroethylene	2,4-Dimethylphenol
1,2-Dichloroethane	m-Cresol
Trans-1,2-Dichloroethylene	Phenol
Cis-1,2-Dichloroethylene	Naphthalene
1,1,1-Trichloroethane	Benzo(a)Anthracene
Methylene Chloride	Flourene
1,1,2-Trichloroethane	Acenaphthene
Trichloroethylene	Anthracene
Chloroform	Dibenzo(a,h)Anthracene
Carbon Tetrachloride	Flouranthene
1,1,2,2-Tetrachloroethane	Pyrene
Tetrachloroethylene	Chrysene
Ethylene Dibromide	2,4-Dinitrophenol
Halogenated Semi-Volatiles	Miscellaneous
1,4-Dichlorobenzene	Coal Tar
1,2-Dichlorobenzene	Creosote
Aroclor 1242, 1260, 1254	
Chlordane	
Dieldrin	
2,3,4,6-Tetrachlorophenol	
Pentachlorophenol	

Note:

The potential for DNAPL release increases with the size and active period of operation for a facility, industrial process, or waste disposal practice.

Occurrence of DNAPL - Decision Chart 2

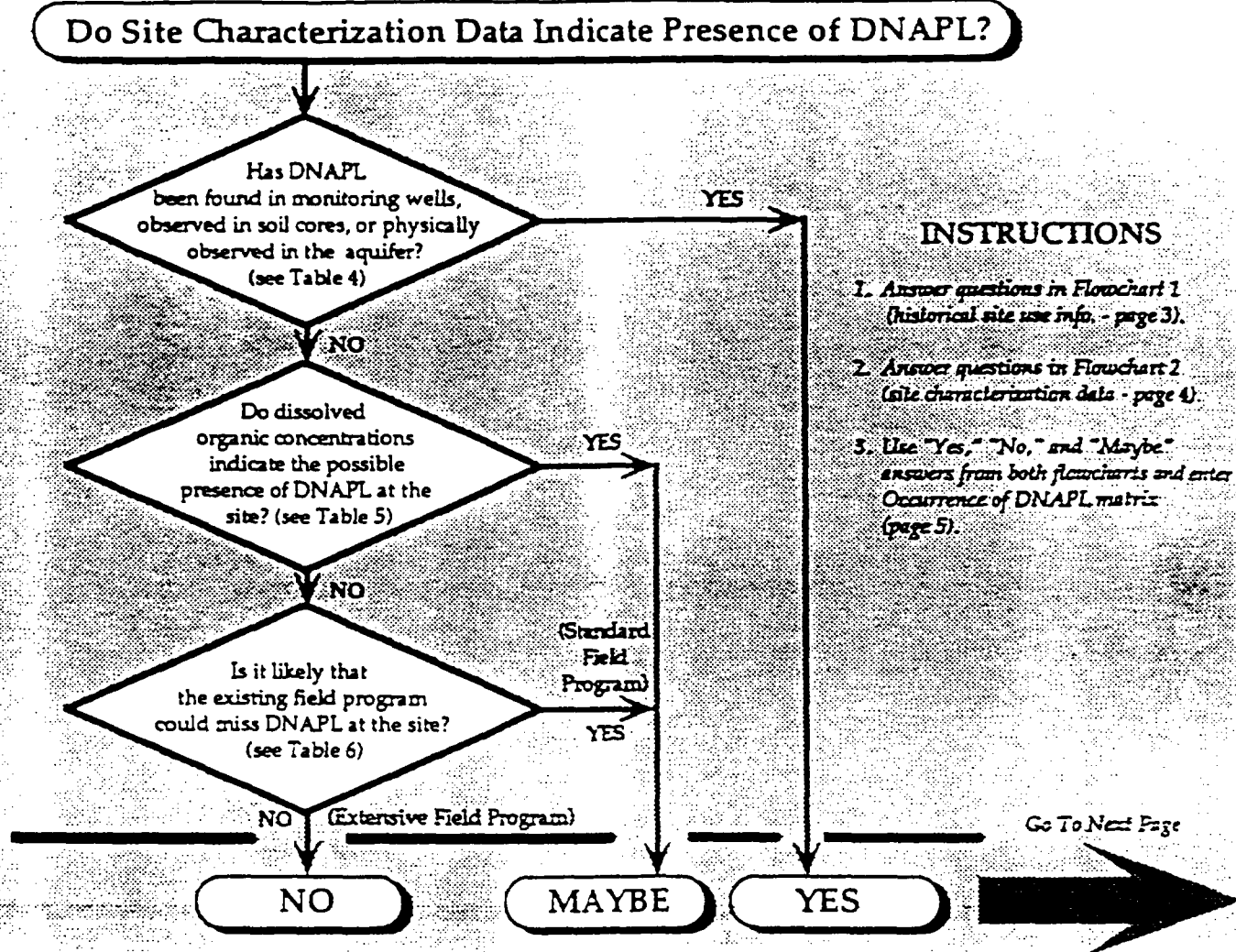


TABLE 4

DNAPL in monitoring wells:
Methods for measuring DNAPL thickness or for collecting DNAPL samples include 1) NAPL/water interface probes that signal a change in the specific conductivity of the borehole fluid, 2) weighted cotton string lowered to the bottom of the well, 3) peristaltic pumps, 4) transparent bottom-loading bailers, and 5) mechanical discrete-depth samplers. In general, the depth of DNAPL accumulation does not provide quantitative information regarding the amount of DNAPL present (26).

DNAPL in soil cores or cuttings:
Visual examination of cores or cuttings may not be effective for confirming the presence of DNAPL except in cases of gross DNAPL contamination. Methods for enhancing visual inspection of soil samples for DNAPL include 1) shaking soil samples in a jar with water to separate the DNAPL from the soil (18) and 2) a paint filter test, where soil is placed in a filter funnel, water is added, and the filter is examined for separate phases (11).

TABLE 5

Conditions that indicate potential for DNAPL at site based on concentration data:

Condition 1:

Contaminant concentrations in groundwater are >
 • 1% of pure phase solubility or
 • 1% of effective solubility if known
 (see Worksheet 1, page 6).

Condition 2:

Organic Concentrations on Soils are > 10,000 mg/kg (equal to 1% of soil mass) (8).

Condition 3:

Contaminant concentrations in groundwater calculated from water/soil partitioning relationships and soil samples are > pure phase solubility or effective solubility (see Worksheet 2, page 6)

Condition 4:

Organic concentrations in groundwater increase with depth (based on data from wells screened at different depths).

Note: These conditions should only be applied for DNAPL-related chemicals in Table 3, Page 3.

TABLE 6

Characteristics of extensive field programs that can confirm the absence of DNAPL (if several are present, select "NO"):

- Numerous monitoring wells
- Multi-level sampling capability.
- Numerous organic chemical analyses of soil samples at different depths using GC or GC/MS methods.
- Well defined site stratigraphy, using a dense network of soil borings, a cone penetrometer survey, or geophysical methods.
- Pilot tests or "early action" projects that indicate the amount of pumping (number of pore volumes) required for groundwater remediation. If greater than would be expected for a dissolved plume alone then DNAPL may be acting as a continuing source of organics to the aquifer.

Potential for Occurrence of DNAPL at Superfund Sites

DNAPL Category

		Do Characterization Data Indicate Presence of DNAPL? (Chart 2)		
		Yes	Maybe	No
Does Historical Use Indicate Presence of DNAPL? (Chart 1)	Yes	I	I-II	II
	Maybe	I	II	II-III
	No	I	II	III

Category

Implications for Site Assessment

- | | |
|--|---|
| <p>I Confirmed or high potential for DNAPL at site.</p> | <ul style="list-style-type: none"> The risk of spreading contaminants increases with the proximity to a potential DNAPL zone. Special precautions should be taken to ensure that drilling does not create pathways for continued vertical migration of free phase DNAPLs. In DNAPL zones, drilling should be suspended when a low-permeability unit or DNAPL is first encountered. Wells should be installed with short screens (≤ 5 feet). If required, deeper drilling through known DNAPL zones should be conducted only by using double or triple cased wells to prevent downward migration of DNAPL. As some DNAPLs can penetrate fractures as narrow as 10 microns, special care must be taken during all grouting, cementing, and well sealing activities conducted in DNAPL zones. The subsurface DNAPL distribution may be difficult to delineate accurately at some sites. DNAPL migrates preferentially through selected pathways (fractures, sand layers, etc.) and is affected by small-scale changes in the stratigraphy of an aquifer. Therefore, the ultimate path taken by DNAPL can be very difficult to characterize and predict. In most cases, fine-grained aquitards (such as clay or silt units) should be assumed to permit downward migration of DNAPL through fractures unless proven otherwise in the field (4). Drilling in areas known to be DNAPL-free should be performed before drilling in DNAPL zones in order to form a reliable conceptual model of site hydrogeology, stratigraphy, and potential DNAPL pathways. In areas where it is difficult to form a reliable conceptual model, an "outside-in" strategy may be appropriate: drilling in DNAPL zones is avoided or minimized in favor of delineating the outside plume (4). Many fractured rock settings may require this approach to avoid opening further pathways for DNAPL migration during site assessment. |
| <p>II Moderate potential for DNAPL at site.</p> | <ul style="list-style-type: none"> Because the potential risk for exacerbating groundwater contamination problems during drilling through DNAPL zones, the precautions described for Category I should be considered during site assessment. Further work should focus on determining if the site is a "DNAPL site." |
| <p>III Low potential for DNAPL at site.</p> | <ul style="list-style-type: none"> DNAPL is not likely to be problem during site characterization, and special DNAPL precautions are probably not needed. Floating free-phase organics (LNAPLs), sorption, and other factors can complicate site assessment and remediation activities, however. |

Worksheet 1: Calculation of Effective Solubility

(from Shiu, 1988 and Feenstra, Mackay, and Cherry, 1991)

For a single component DNAPL, the pure-phase solubility of the organic constituent can be used to estimate the theoretical upper-level concentration of organics in aquifers or for performing dissolution calculations. For mixed DNAPLs, however, the effective solubility concept should be employed using the following relationship:

$$S_i^e = X_i S_i$$

Where

S_i^e = the actual aqueous dissolved phase concentration in mg/l

X_i = the mole fraction of component i in the DNAPL mixture (obtained from a laboratory analysis of a DNAPL sample)

S_i = the pure-phase solubility of compound i in mg/l (usually obtained from literature sources)

For example, if a laboratory analysis indicates that the mole fraction of trichloroethylene in DNAPL is 0.10, then the effective solubility would be 110 mg/l [pure phase solubility of TCE times mole fraction TCE: (1100 mg/l) * (0.10) = 110 mg/l]. Effective solubilities can be calculated for all components in a DNAPL mixture. Some DNAPLs contain organic constituents that are practically insoluble, such as long-chained alkanes. These insoluble components will reduce the mole fraction and effective solubility of more soluble organics but will not contribute dissolved-phase organics to groundwater.

Worksheet 2: Method for Assessing Residual NAPL Based on Organic Chemical Concentrations in Soil Samples (From Feenstra, MacKay, and Cherry, 1991)

To estimate if NAPLs are present in the soil, a partitioning calculation can be applied based on chemical and physical analyses of soil samples. The method assumes that all of the organics in the subsurface are either in the dissolved in groundwater or adsorbed to soil (assuming dissolved-phase sorption, not the presence of NAPL).

By using the concentration of organics on the soil and the partitioning calculation, a calculated pore-water concentration of organics in groundwater is determined. If the calculated pore-water concentration is greater than the estimated solubility of the organic constituent of interest, then DNAPL may be present at the site. For soil samples collected in the saturated zone, the following calculations can be applied (see Feenstra, MacKay, and Cherry (1991) for a full description of the methodology):

Step 1: Calculate S_i^e , the effective solubility of organic constituent of interest.

See Worksheet 1, above.

Step 2: Determine Koc, the organic carbon-water partition coefficient from

A) Literature sources (such as 24) or

B) From empirical relationships based on Kow, the octanol-water partition coefficient, which is also found in the literature (24). For example, Koc can be estimated from Kow using the following expression developed for polyaromatic hydrocarbons (13):

$$\log Koc = 1.0 \cdot \log Kow - 0.21$$

Other empirical relationships between Koc and Kow are presented in ref. 6 and 19.

Step 3: Determine foc, the fraction of organic carbon on the soil, from a laboratory analysis of clean soils from the site.

Values for foc typically range from 0.03 to 0.00017 mg/mg (6). Convert values reported in percent to mg/mg.

Step 4: Determine or estimate pb, the dry bulk density of the soil, from a soils analysis. Typical values range from 1.8 to 2.1 gms/cc (kg/l). Determine or estimate ϕ_w , the water-filled porosity.

Step 5: Determine Kd, the partition coefficient (also called the distribution coefficient) between the pore water (groundwater) and the soil solids using:

$$Kd = Koc \cdot foc$$

Step 6: Using Ct, the measured soil chemical concentration in mg/kg, calculate Cw: (Cw = calculated pore water conc. in mg/l assuming no DNAPL is present)

$$Cw = \frac{(Ct \cdot pb)}{(Kd \cdot pb + \phi_w)}$$

Step 7: Compare Cw and S_i^e (from Step 1):

$Cw > S_i^e$ indicates possible presence of DNAPL

$Cw < S_i^e$ indicates possible absence of DNAPL

GLOSSARY (adapted from Cherry, 1991):

DNAPL: A Dense Non-aqueous Phase Liquid. Also known as free product or a sinking plume (sinker).

DNAPL ENTRY LOCATION: The area where DNAPL has entered the subsurface.

DNAPL SITE: A site where DNAPL has been released and is now present in the subsurface as an immiscible phase.

DNAPL ZONE: The portion of a site affected by free-phase or residual DNAPL in the subsurface (either the vadose zone or saturated zone). The DNAPL zone has organics in the vapor phase (unsaturated zone), dissolved phase (both unsaturated and saturated zone), and DNAPL phase (both unsaturated and saturated zone).

DISSOLUTION: The process where soluble organic components from DNAPL dissolves in groundwater or infiltration and forms a groundwater contaminant plume. The duration of remediation measures (either clean-up or containment) is determined by the 1) the rate of the dissolution process that can be achieved in the field, and 2) the mass of soluble components in the residual DNAPL trapped in the aquifer.

EFFECTIVE SOLUBILITY: The actual aqueous solubility of an organic constituent in groundwater that is in chemical equilibrium with a mixed DNAPL (a DNAPL containing several organic constituents). The effective solubility of a particular organic chemical can be estimated by multiplying its mole fraction in the DNAPL mixture by its pure phase solubility (see Worksheet 1, page 7).

FREE-PHASE DNAPL: Immiscible liquid existing in the subsurface with a positive pressure such that it can flow into a well. If not trapped in a pool, free phase DNAPL will flow vertically through an aquifer or laterally down sloping fine-grained stratigraphic units. Also called mobile DNAPL or continuous phase DNAPL.

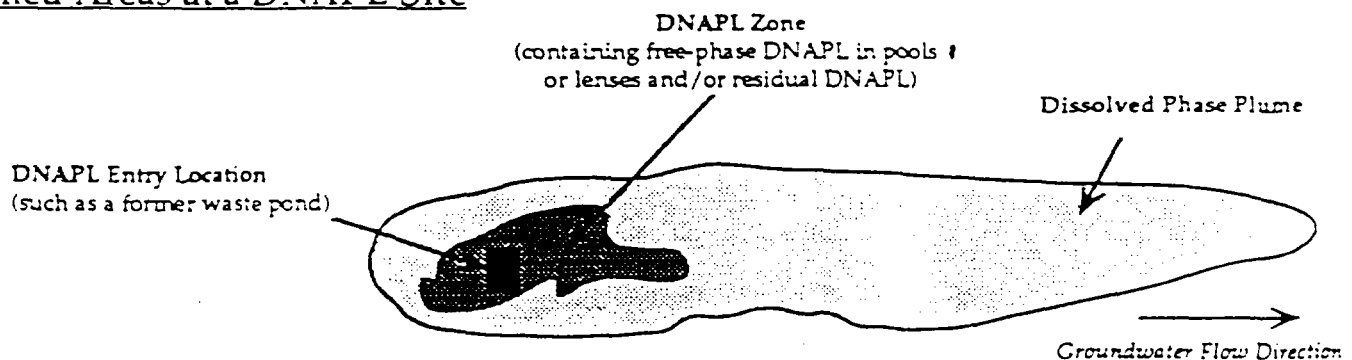
PLUME: The zone of contamination containing organics in the dissolved phase. The plume usually will originate from the DNAPL zone and extend downgradient for some distance depending on site hydrogeologic and chemical conditions. To avoid confusion, the term "DNAPL plume" should not be used to describe a DNAPL pool; "plume" should be used only to refer to dissolved-phase organics.

POOL and LENS: A zone of free-phase DNAPL at the bottom of an aquifer. A lens is a pool that rests on a fine-grained stratigraphic unit of limited areal extent. DNAPL can be recovered from a pool or lens if a well is placed in the right location.

RESIDUAL: Immiscible phase liquid held in the pore spaces or fractures by capillary forces (negative pressure on DNAPL). Residual will remain trapped within the pore of the porous media unless the viscous forces (caused by the dynamic force of water against the DNAPL) are greater than the capillary forces holding the DNAPL in the pore. At most sites the hydraulic gradient required to mobilize all of the residual trapped in an aquifer is usually much greater than can be produced by wells or trenches (27).

RESIDUAL SATURATION: The fraction of available pore space containing residual DNAPLs, or the saturation level where free-phase DNAPL becomes residual DNAPL (18). In the vadose zone, residual saturation range up to 20% of total pore volume while in the saturated zone residual saturations range up to 50% of total pore volume.

Defined Areas at a DNAPL Site



REFERENCES

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